ATLAS Electron ID

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How to identify electrons?

Calorimeter EM cluster

+

Inner Detector track

+

Good spatial and energy match of cluster and track

ATLAS Electron ID

- EM Barrel and Endcap Calorimeters
- Performance in Test Beam
- EM Clusters
- Electron ID Cuts
- Electron ID Results

EM Calorimeter Requirements

Radiation hard
Large rapidity coverage and full azimuthal coverage
Hermetic (no cracks)
Large dynamic range (30 MeV, to 1 TeV for a 5 TeV Z'/W')
Long term stability
Fast signal response (bunch crossing @ 25 ns); Linear signal response
Fine longitudinal & transverse segmentation (particle ID, spatial/angular resolution)

And:

Excellent energy resolution:

For a 1% resolution on M_H in $H \rightarrow \gamma\gamma$, $H \rightarrow 4e$ (for $M_H < 180$ GeV) need:

Sampling term **~ 10%/√E (GeV)** (statistical fluctuations in shower)

Constant term **< 0.7%** (mechanical & calibration non-uniformities)

Angular resolution: **<50 mrad/√E (GeV)**, to measure γ directions in η for precise M_H in $H \rightarrow \gamma\gamma$, and measure non-vertex-pointing photons (GMSB).

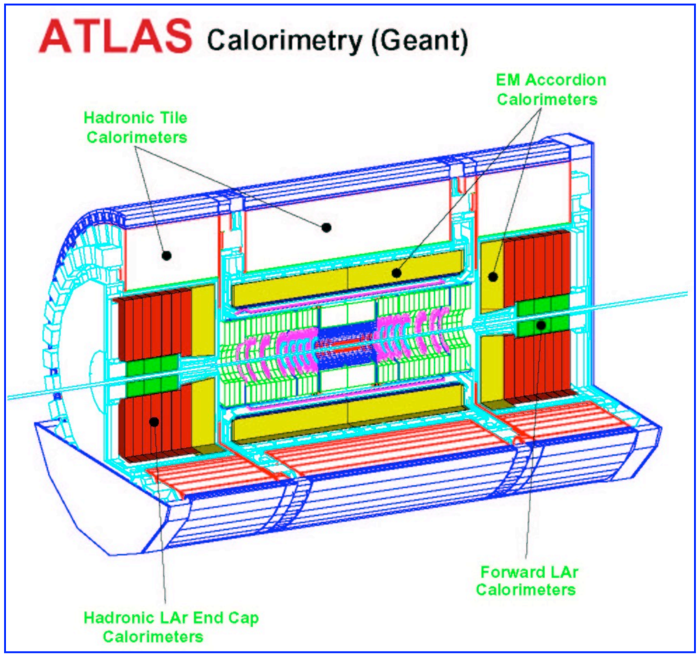
π^0 rejection (π^0 faking γ) **> 3**, to detect $H \rightarrow \gamma\gamma$.

Jet rejection (jets faking electrons) **> 10^5**, for exclusive electron sample.

Time measurement <100 ps for beam-gas background rejection, Z_{vertex} from endcap events, pile-up rejection, long-lived particles.

ATLAS LAr Calorimeters

Requirements can be met with a **lead-liquid argon sampling calorimeter**, with **accordion geometry**.

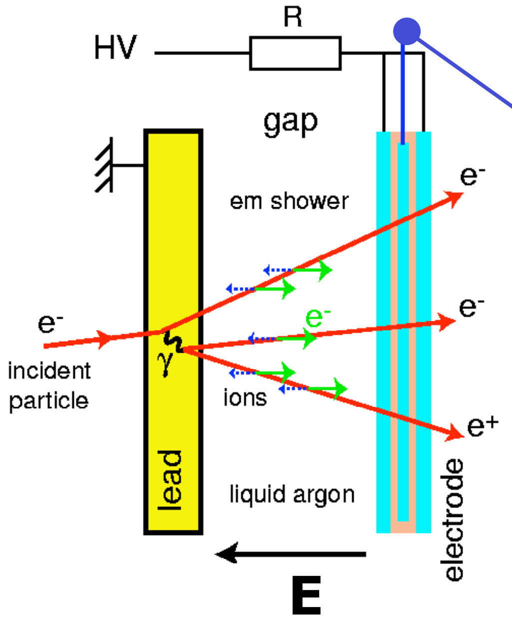


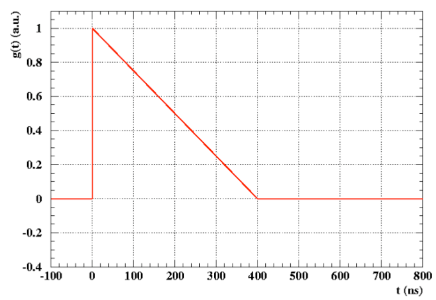
EM Calorimeters (in yellow):

EM Barrel: $|\eta| < 1.475$

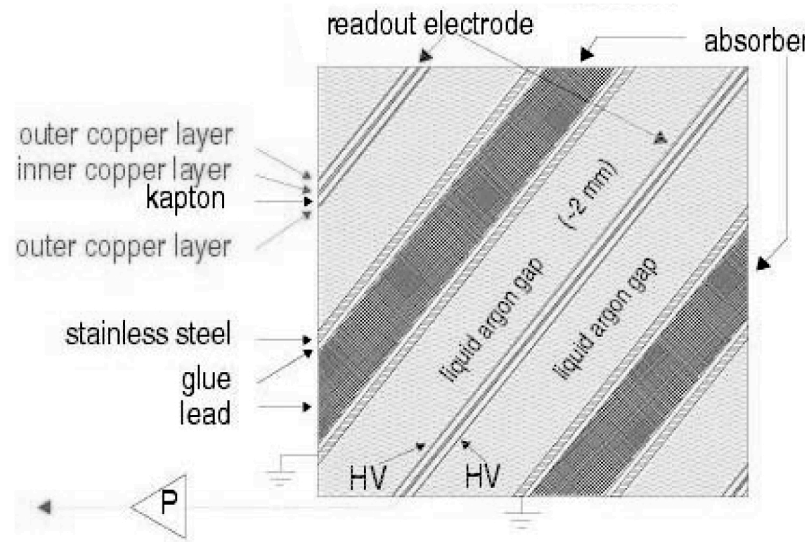
EM Endcap: $1.375 < |\eta| < 3.2$

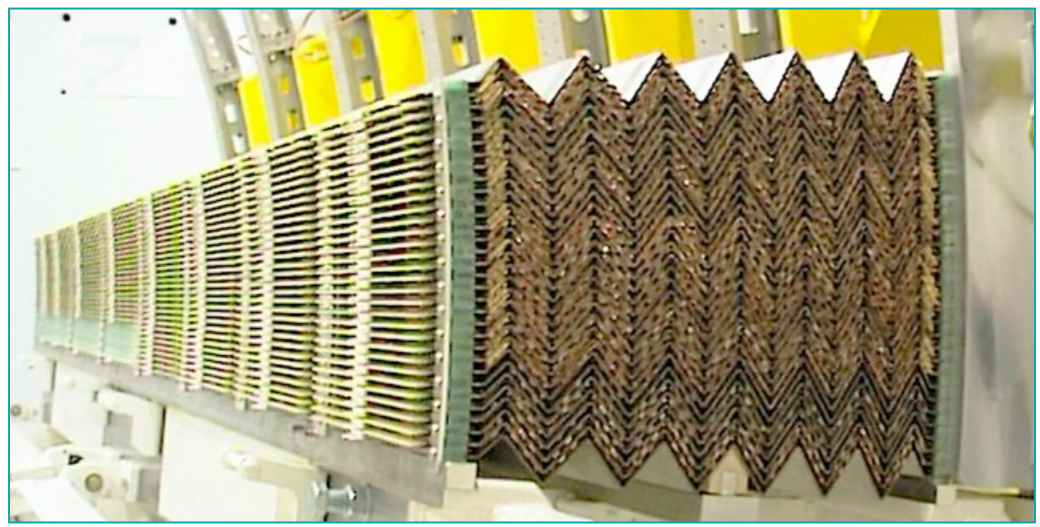
EM LAr Accordion Calorimeter



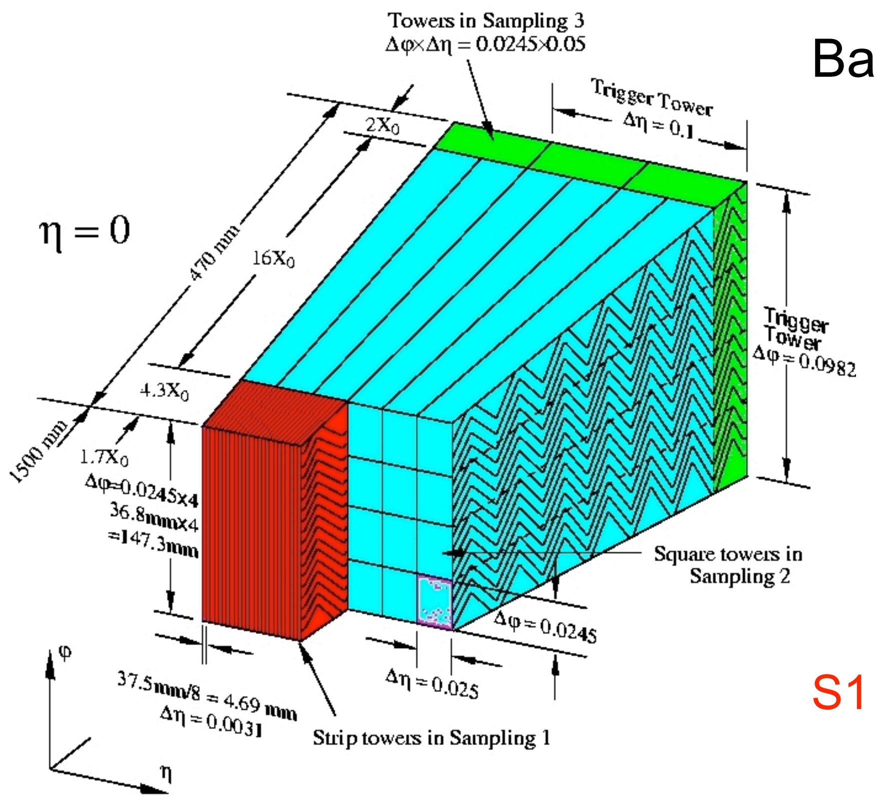


t_{drift} =450 ns





Longitudinal & Transverse Segmentation



Barrel calorimeter segmentation:

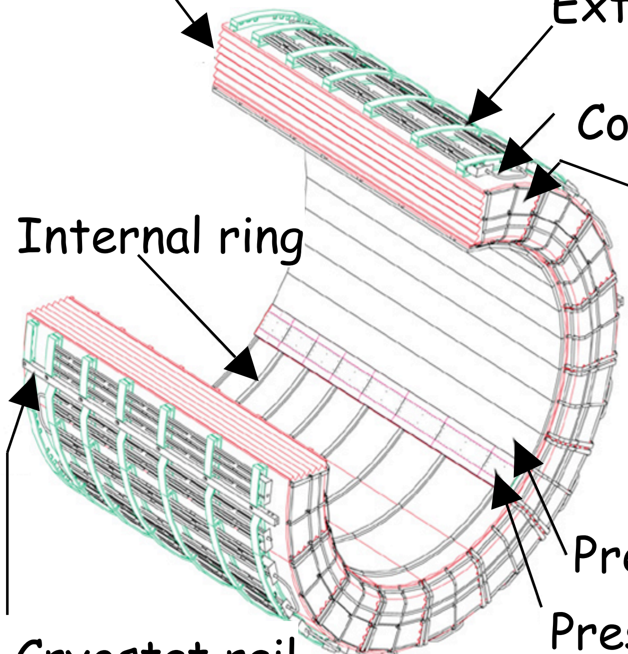
S3 (Back): $\Delta\phi \times \Delta\eta$=**0.025 x 0.050**
$2\ X_0$
High energy shower tails.
Hadron/EM separation.

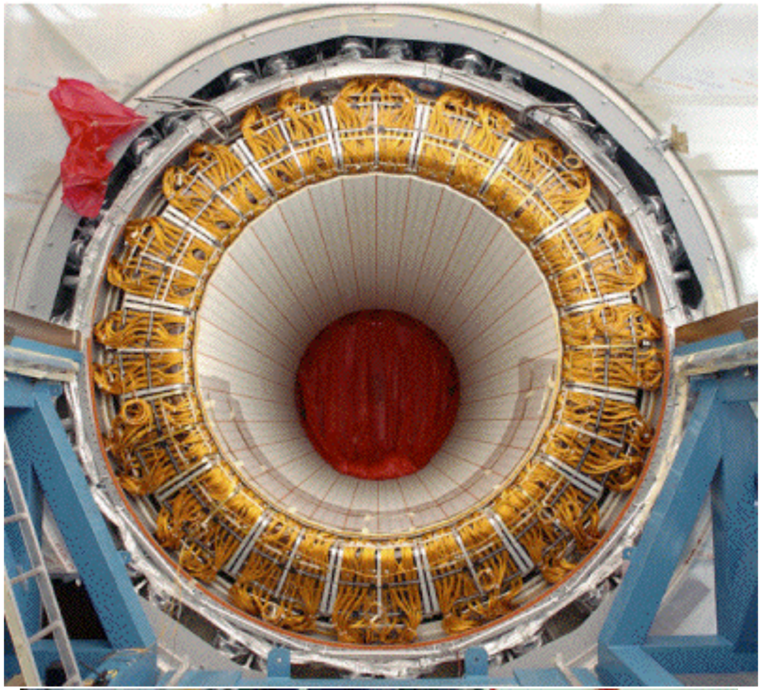
S2 (Middle): $\Delta\phi \times \Delta\eta$=**0.025 x 0.025**
$16\ X_0$
Main energy measurement.

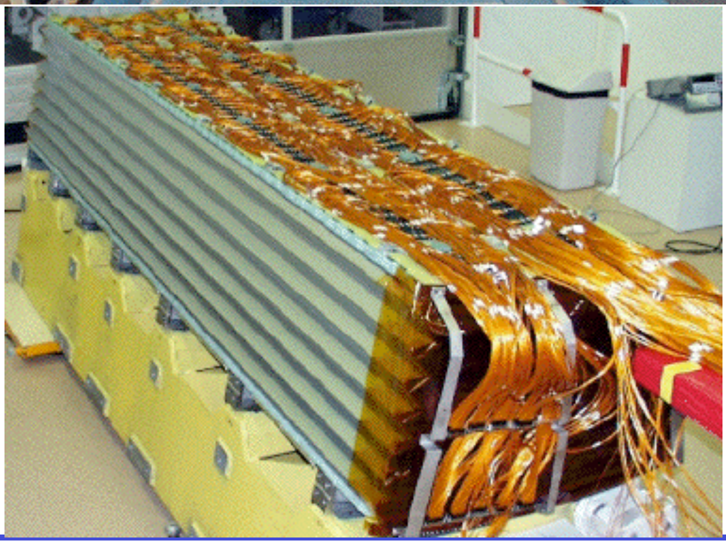
S1 (Strips): $\Delta\phi \times \Delta\eta$=**0.100 x 0.003**
$6\ X_0$ ($1.7\ X_0$ dead + $4.3\ X_0$ live)
γ/π^0 separation.
η position measurement.

Pre-sampler (not shown): $|\eta| < 1.8$; 11 mm LAr.
Correct for energy lost in dead material in front of calorimeter.

EM Barrel Calorimeter







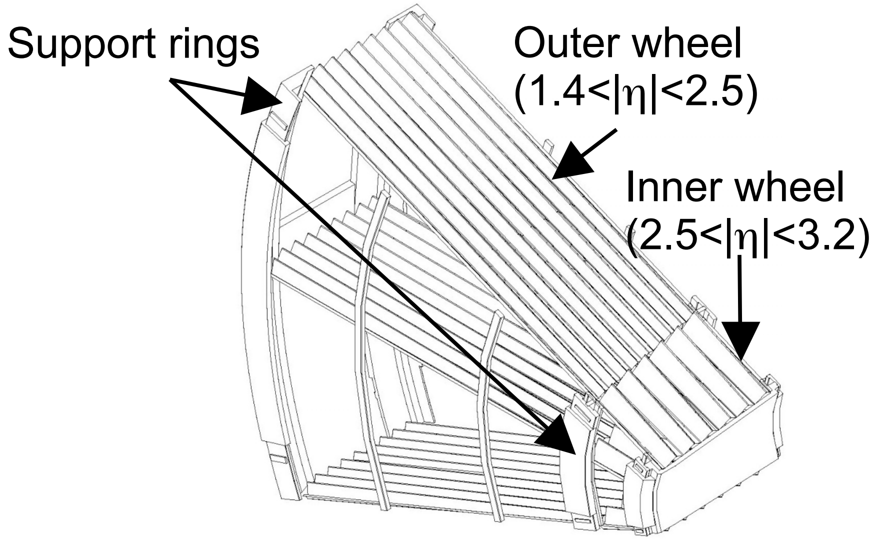
Barrel is 7 m long, with OD=4 m. It is split in half at η=0 (2 “wheels”).

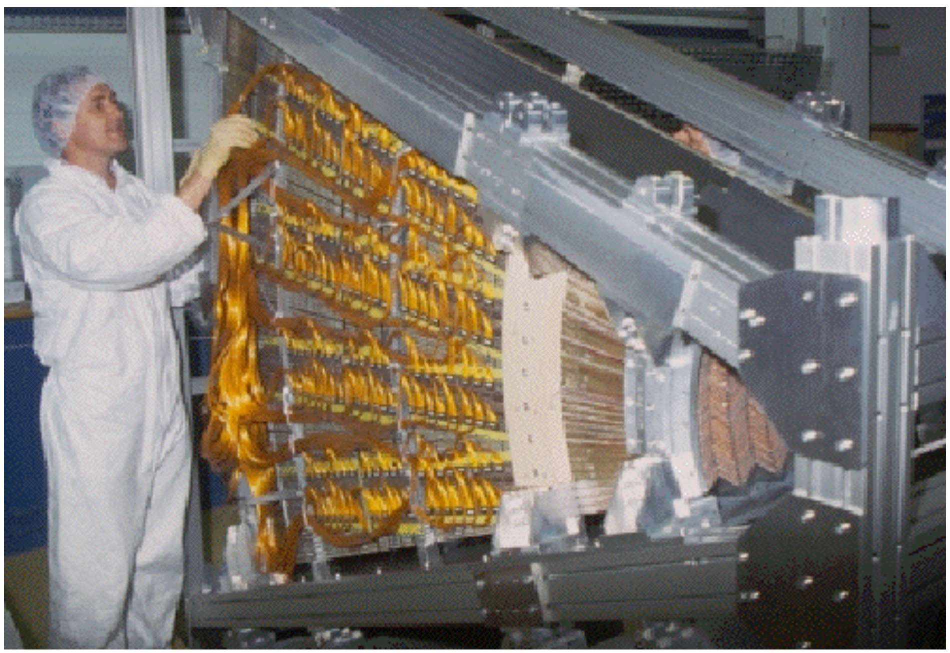
16 modules/wheel.

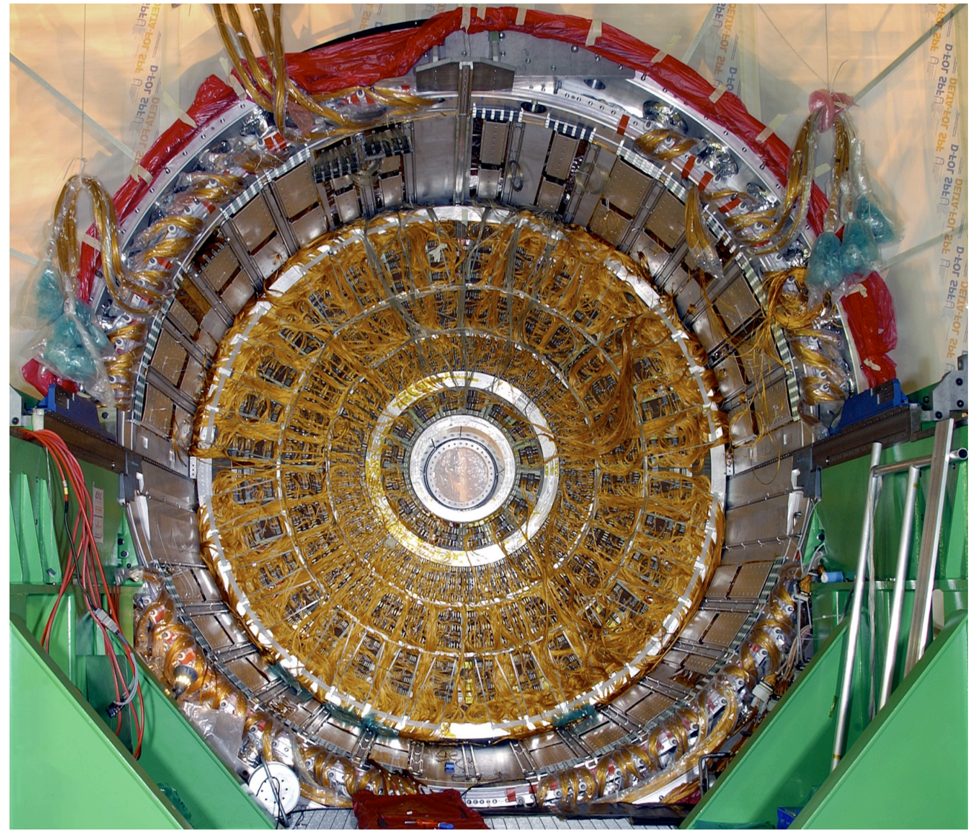
Each module is 3.5 m long, 0.5 m deep, and is 3.5 tons.

Fully assembled and in cryostat.

EM Endcap Calorimeter





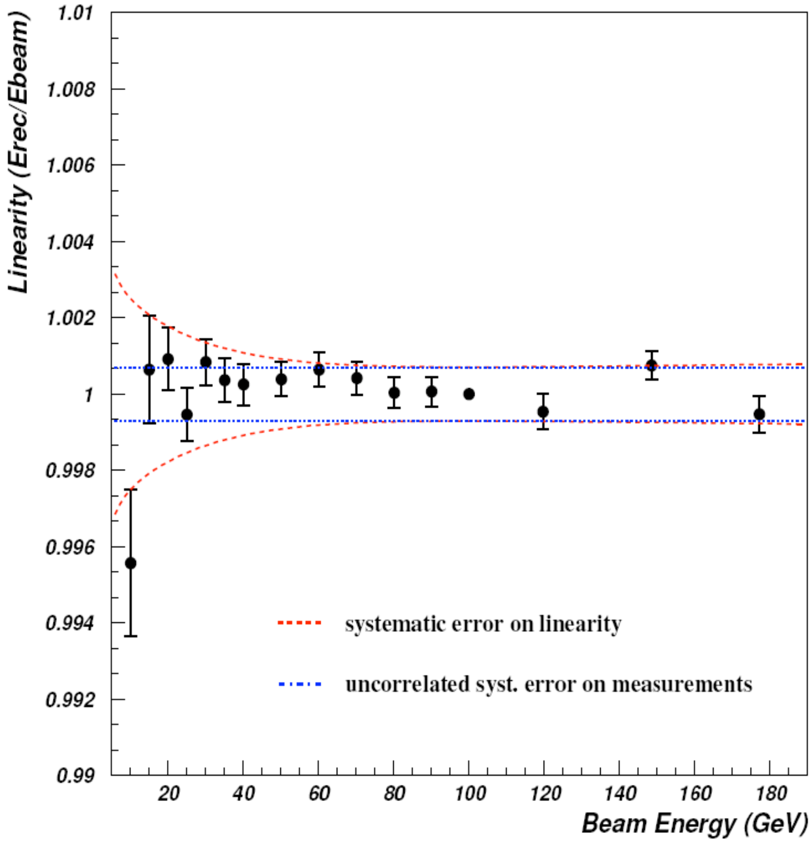


2 endcap calorimeters, OD=4 meters.
8 wedge-shaped modules/endcap.
Increased complexity:
- LAr gap varies with radius
- Varying HV, in 9 steps

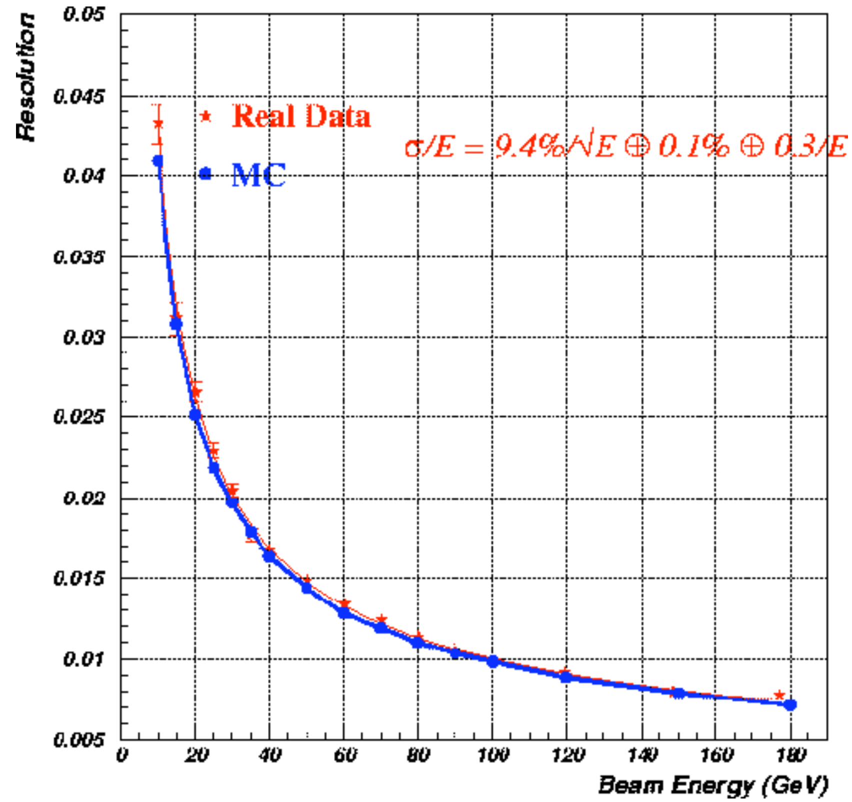
Both endcaps fully assembled.

Barrel Energy Linearity and Resolution

Energy Response Linearity



Energy Resolution



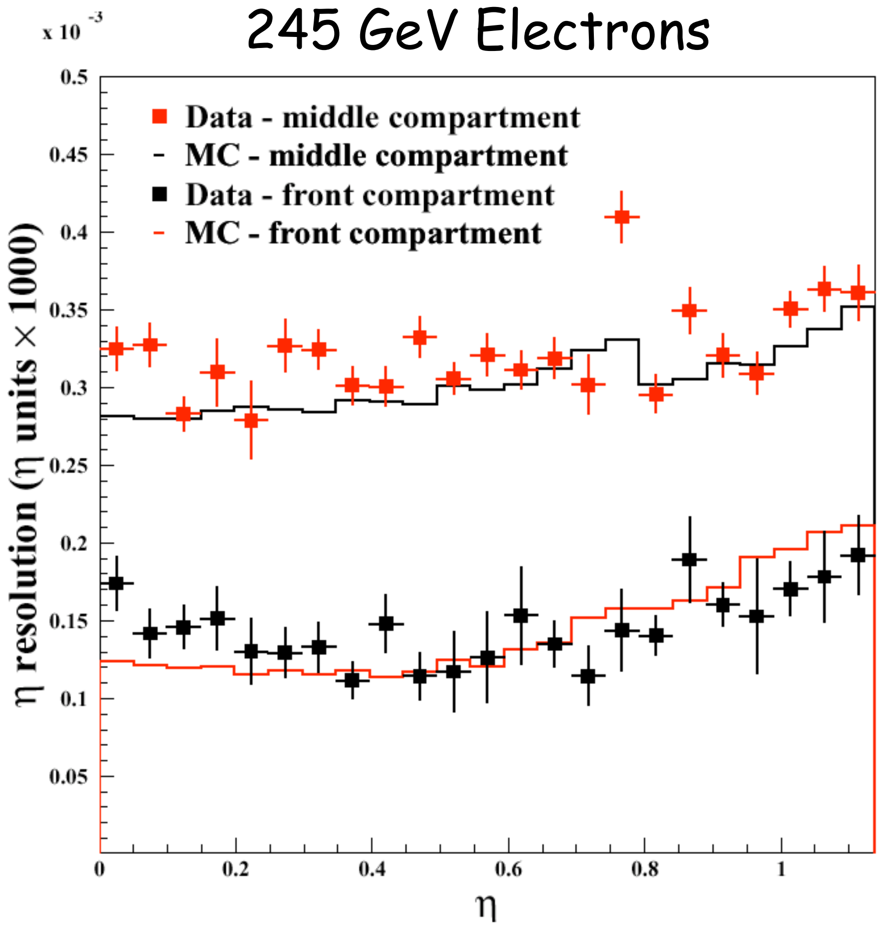
Linear within 0.25% for E>10 GeV
within 0.10% for E>40 GeV

Sampling term = **9.4%/√E (GeV)**
Energy resolution agrees with MC

Performance in Test Beam

Barrel Position Resolution

245 GeV Electrons



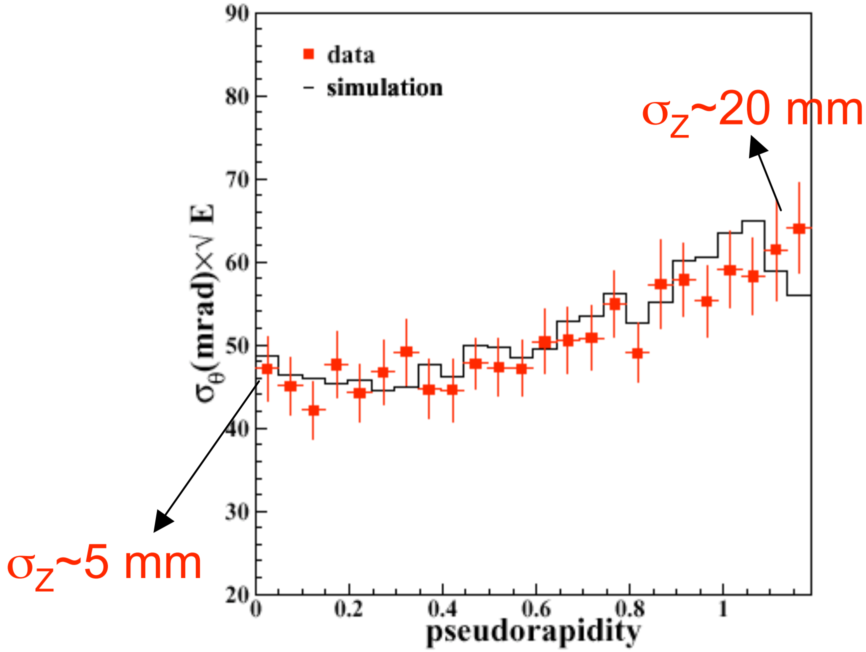
~550 μm at η=0

~250 μm at η=0

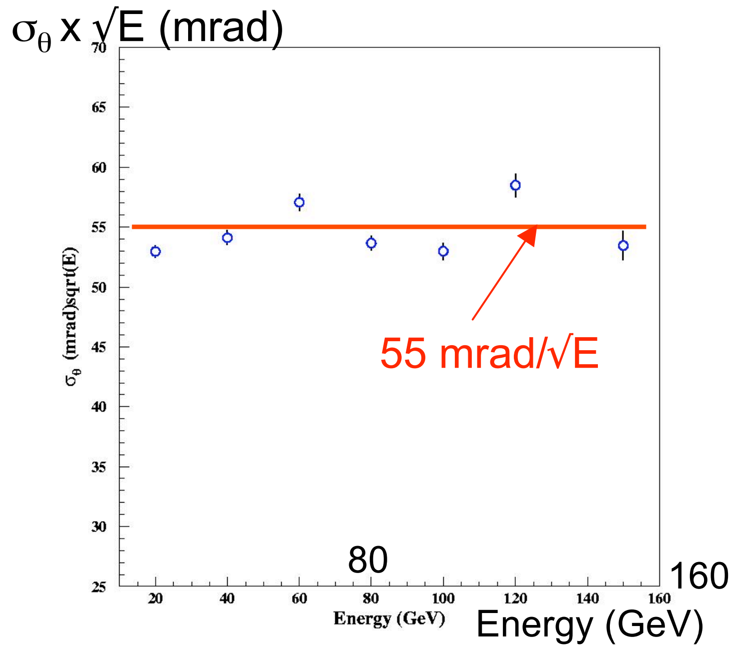
Similar performance for endcap.

Angular Resolution

Barrel E=245 GeV



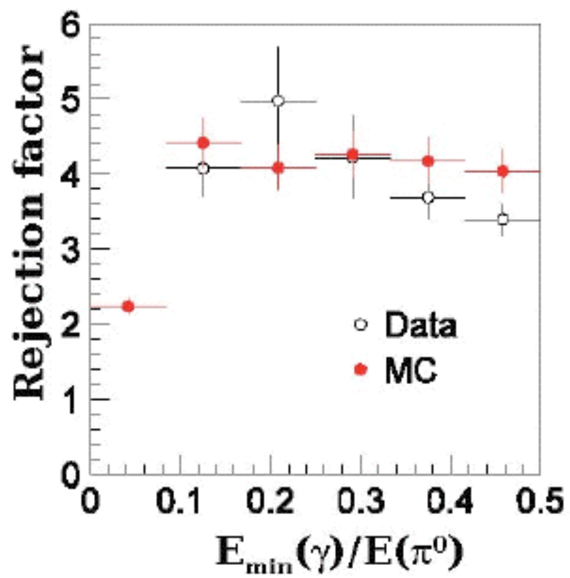
Endcap η~1.8



H→γγ vertex reconstructed with 2-3 cm accuracy in ATLAS.
LHC interaction point: σ_Z ~ 5.6 cm.

γ-π^0 Separation

Needed for 2-jets background rejection in $H \rightarrow \gamma\gamma$ search.
Strip section has been designed to rejects jets with leading π^0;
resolution σ_η = 0.00015.
Seek double cluster in strips.

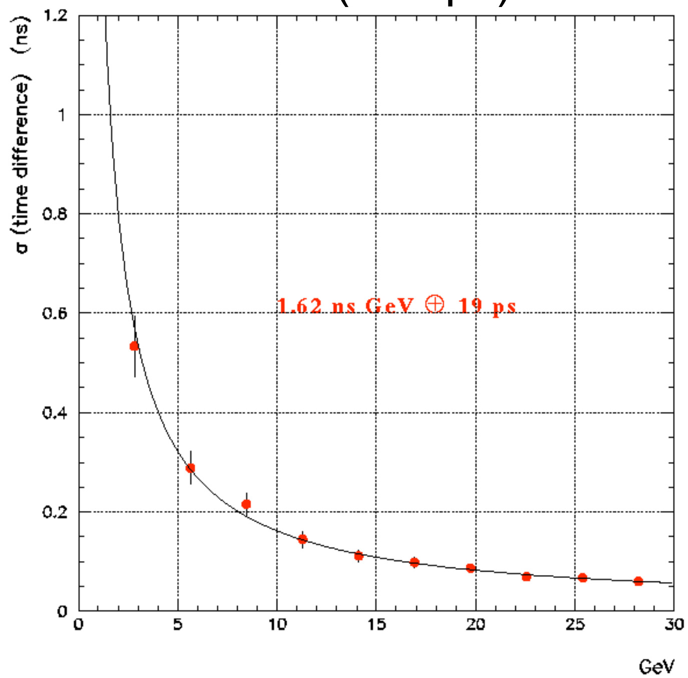


Good agreement with MC; better than design requirement (rejection >3)

Time Measurement

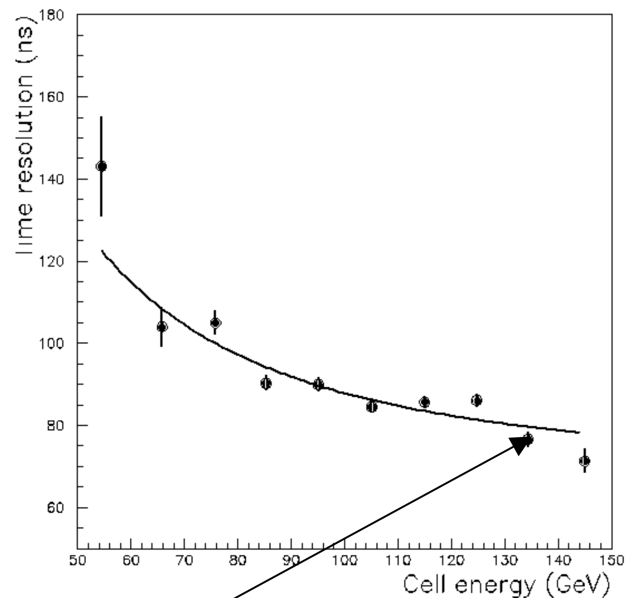
Exploits very fast signal in LAr. Useful for beam-gas background rejection, Z_{vertex} from endcap events, pile-up rejection, and long-lived particles.

FE electronics resolution has a very low constant term (<20 ps)



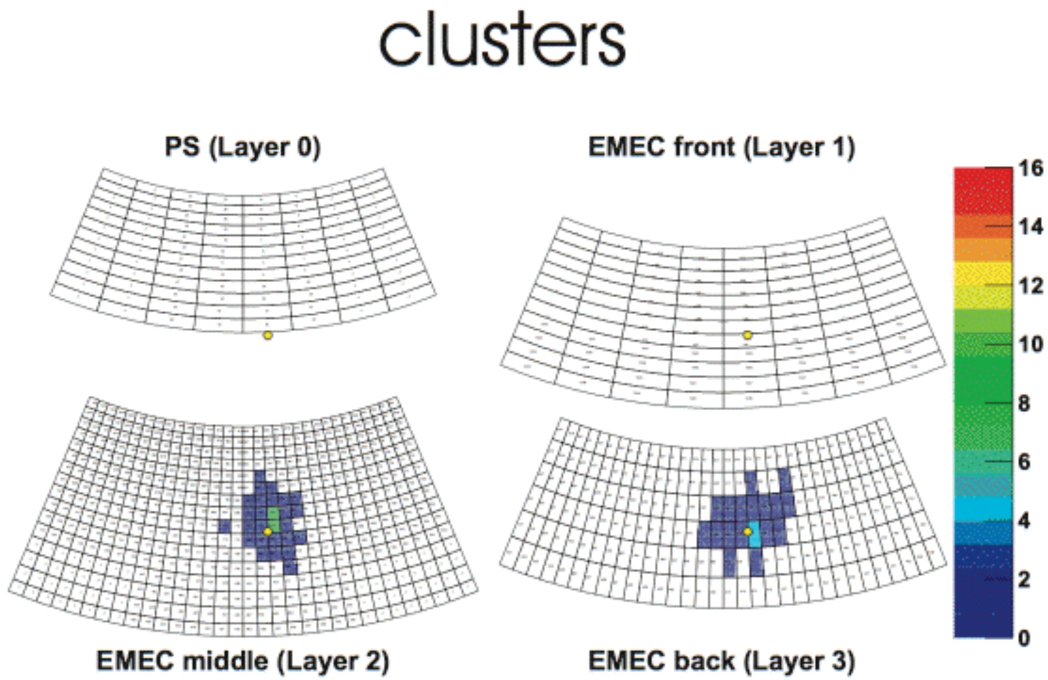
1.62 ns.GeV ⊕ 19 ps

245 GeV electrons in TB



~70 ps constant term

Electron ID - Clusters



Cluster finding:
•Towers are created by summing the cells of the pre-sampler and the 3 EM calorimeter layers in depth.
•A "sliding window algorithm", using a 5x5 window (0.125x0.125), is used to find clusters. The window slides in the towers η-φ grid to find local energy peaks.

Cluster definition: Once the local energy peak is found, the algorithm clusters the energy in a fixed window size around the found peak. The current default is a 5x5 window, but 3x5 and 3x7 windows are also used.

Other cluster finding algorithms can be used: nearest neighbor, cone, cell based (instead of tower based), 3D nearest neighbor, etc.

Electron ID - Cluster Corrections

Many very detailed EM cluster corrections are then made to correct various biases:

η position correction (η measurements are biased towards the cell center; correct bias in strips and middle layers).

ϕ position correction (correct ϕ position bias in middle layer).

ϕ energy modulation correction (measured energy varies slightly depending on the position of the particle impact relative to the accordion structure of the absorbers, since the amount of absorber varies with ϕ because of finite bending radius of the accordion).

η energy modulation correction (have a small dependence of response on the η offset within a cell).

Intercryostat gap correction (Correct for the energy lost in the gap between the cryostats, using the tile calorimeter scintillator to recover some of the energy).

Layer weights correction (determine layer weights for 10.0.1)

Electron ID Cuts for AnalysisObjectData

Pt cut:

```
(electron->pt()>15*GeV )
```

Eta cut:

```
(fabs(electron->eta())<2.5)
```

Isolation cut:

```
(electron->parameter(ElectronParameters::etcone20) < 10.*GeV )
```

Require matching track:

```
(electron->hasTrack()!=0)
```

Shower shape:

```
(electron->isEM()%16 == 0 )
```

E/p cut:

```
(electron)->parameter(ElectronParameters::EoverP)>0.5 &&
(electron)->parameter(ElectronParameters::EoverP)<4.0
```

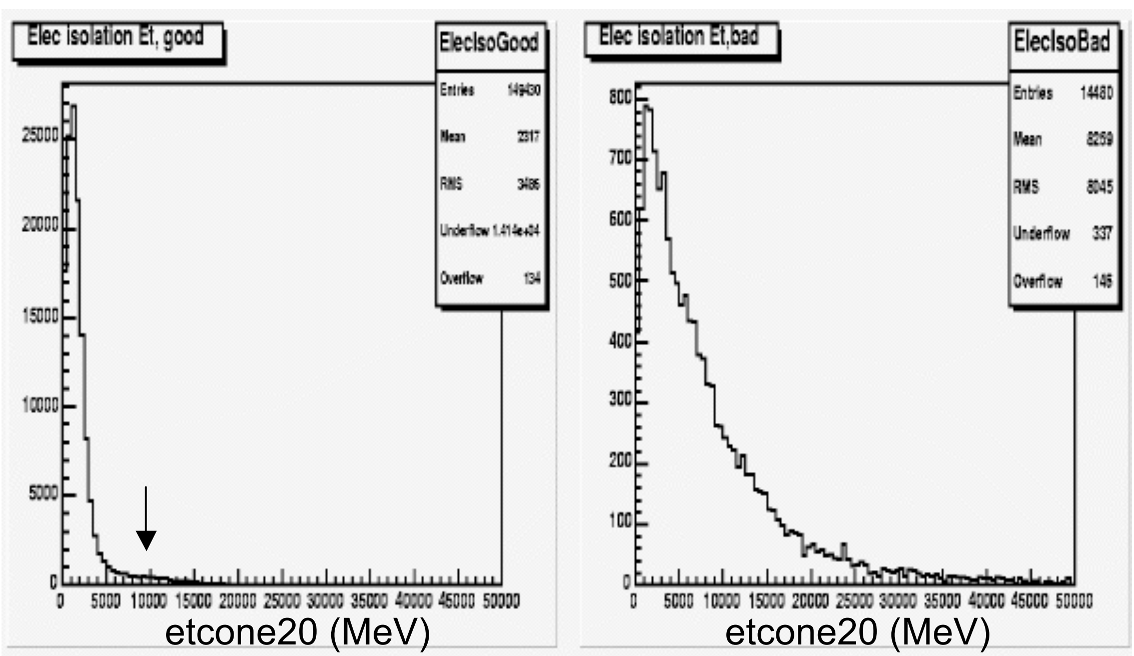
Other electron ID algorithms are being developed: likelihood, H-matrix, etc.

Electron ID Cuts

Isolation cut: (electron->parameter(ElectronParameters::etcone20) < 10.*GeV)

etcone20 = Total E_T in 0.2 cone around centroid - EM Cluster E_T (i.e. 5x5 of EM layers only around centroid).

Currently this is a very strange cut, as it uses E_T instead of E, and also because it cuts on the excess energy, and not the excess energy as a function of the cluster energy (so the cut has an energy dependence). D0 used isolation=$[E_{tot}(0.4)-E_{em}(0.2)]/E_{em}(0.2)$.



Z(→ee) + jets MC

Good match means that the reconstructed electron matches a truth electron from Z-decay, within ΔR=0.1. Bad means it didn't match.

Electron ID Cuts

Require matching track: (electron->hasTrack()!=0)

Require a good quality track pointing to an EM cluster with a good spatial match.

$|\Delta\eta| = |\eta^{strips} - \eta^{ID}| < 0.005$, where η^{strips} is calculated with the strips of the EM calorimeter and η^{ID} is calculated using the Inner Detector.

$|\Delta\phi| = |\phi^{middle} - \phi^{ID}| < 0.02$, where ϕ^{middle} is calculated with the middle layer of the EM calorimeter and ϕ^{ID} is calculated using the Inner Detector.

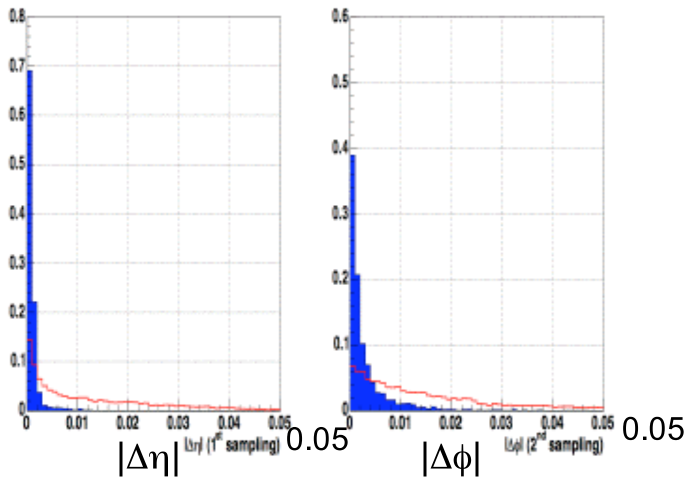


Figure 7: *Angular matching between charged tracks extrapolated to the electromagnetic calorimeter and electromagnetic clusters in pseudorapidity ($|\Delta\eta|$) and azimuth ($|\Delta\phi|$). The distributions are shown for jets (empty histogram) and electrons (full histogram) at low luminosity. Only the LVL1 trigger is applied beforehand. The distributions are normalised to unit area.*

Electron ID Cuts

Shower shape: (electron->isEM()%16 == 0)

isEM is a word, whose bits represent various conditions. The definitions are:

```
enum BitDef {
  // Cluster based egamma
  ClusterEtaRange        =  0,
  ClusterHadronicLeakage =  1,    // see plots
  ClusterMiddleSampling  =  2,    // see plots
  ClusterFirstSampling   =  3,    // see plots
  //Track based egamma
  TrackEtaRange          =  8,
  TrackHitsA0            =  9,
  TrackMatchAndEoP       = 10,
  TrackTRT               = 11
};
```

If a bit is on, it means the electron failed the cut. isEM ==0 means it passed all the cuts. In Rome production, TRT simulation did not work right, so the TrackTRT cuts should not be applied. (electron->isEM()%16 == 0) means only calorimeter cluster cuts are applied.

Electron ID Cuts

ClusterHadronicLeakage:

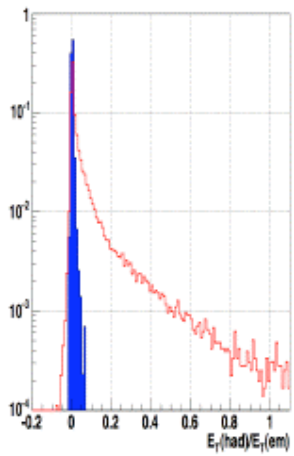


Figure 2: *Hadronic leakage, defined as the ratio of the transverse energy deposited in a window $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ in the first compartment of the hadronic calorimeter divided by the transverse energy deposit in the electromagnetic calorimeter. The distributions are shown for jets (empty histogram) and electrons (full histogram) at low luminosity. Only the* LVL1 *trigger is applied beforehand. The distributions are normalised to unit area.*

ClusterMiddleSampling

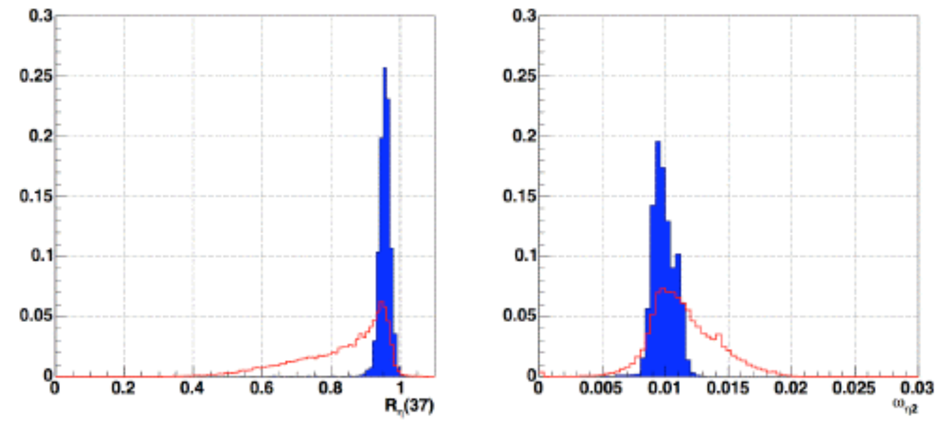
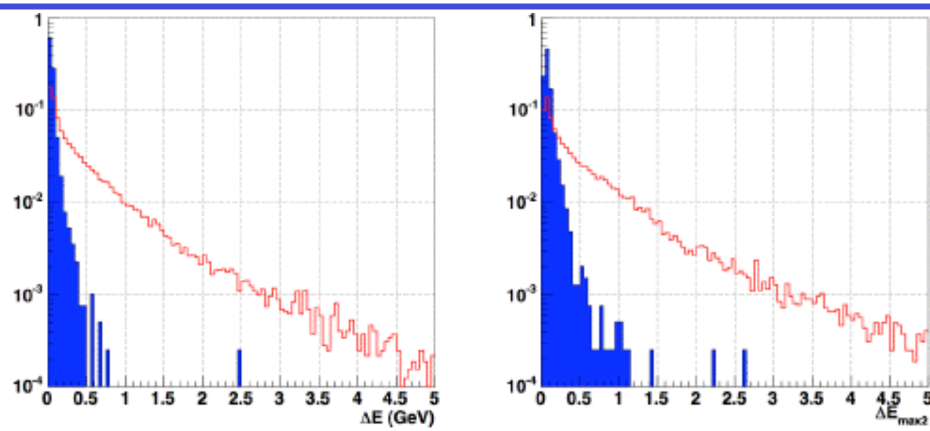


Figure 3: *Lateral shower shape $R_\eta(37)$ (left panel) and lateral width $\omega_{\eta 2}$ (right panel). The distributions are shown for jets (empty histogram) and electrons (full histogram) at low luminosity. Only the* LVL1 *trigger is applied beforehand. The distributions are normalised to unit area.*

Electron ID Cuts



ClusterFirstSampling

Figure 4: *On left panel : Difference* ΔE *between the energy associated with the second maximum* E_{max2} *and the energy deposited in the strip with the minimal value between the first and second maximum* (E_{min}). *On right panel :* ΔE_{max2}. *The distributions are shown for jets (empty histogram) and electrons (full histogram) at low luminosity. Only the* LVL1 *trigger is applied beforehand. The distributions are normalised to unit area.*

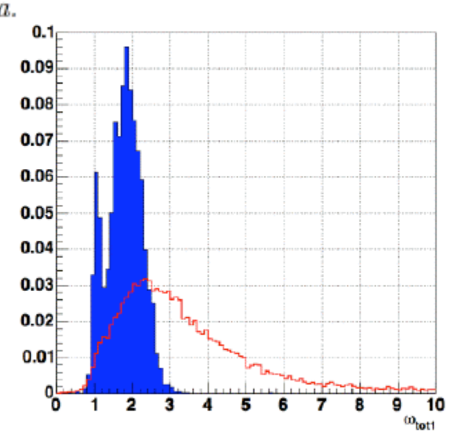
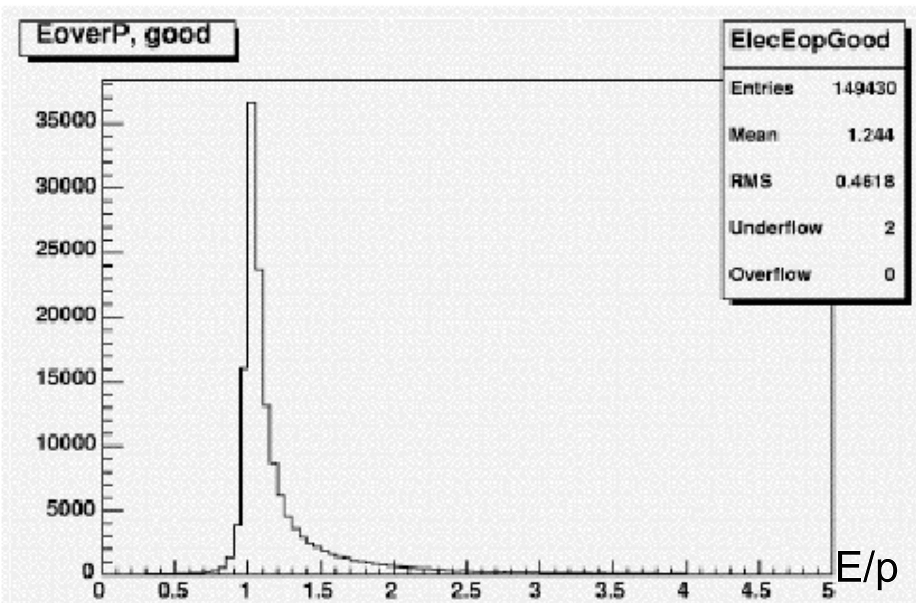
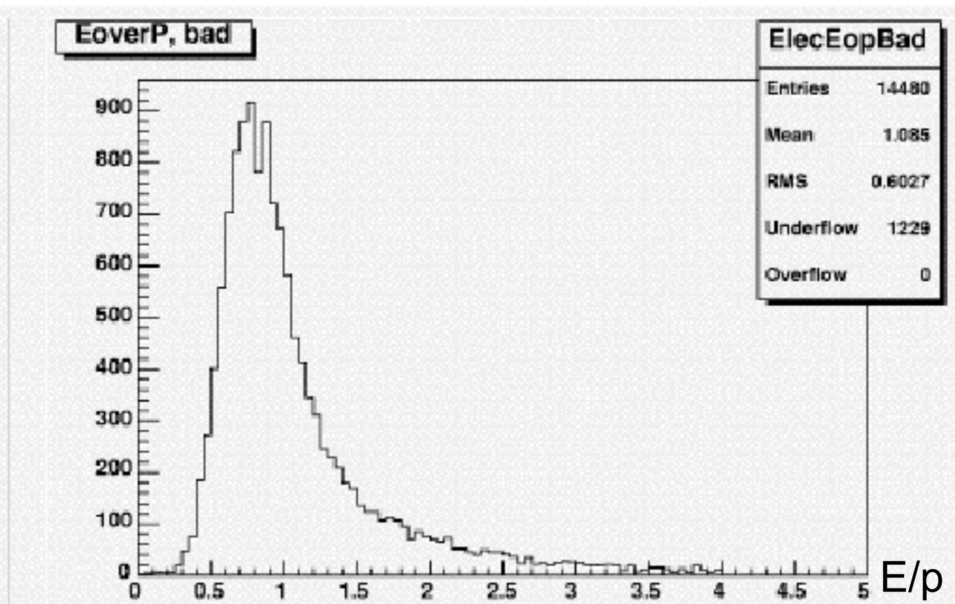


Figure 5: *Total shower width* ω_{tot1} *in the first compartment of the electromagnetic calorimeter. The distributions are shown for jets (empty histogram) and electrons (full histogram) at low luminosity. Only the* LVL1 *trigger is applied beforehand. The distributions are normalised to unit area.*

Electron ID Cuts

E/p cut:
(electron)->parameter(ElectronParameters::EoverP)>0.5 &&
(electron)->parameter(ElectronParameters::EoverP)<4.0





Z(→ee) + jets MC

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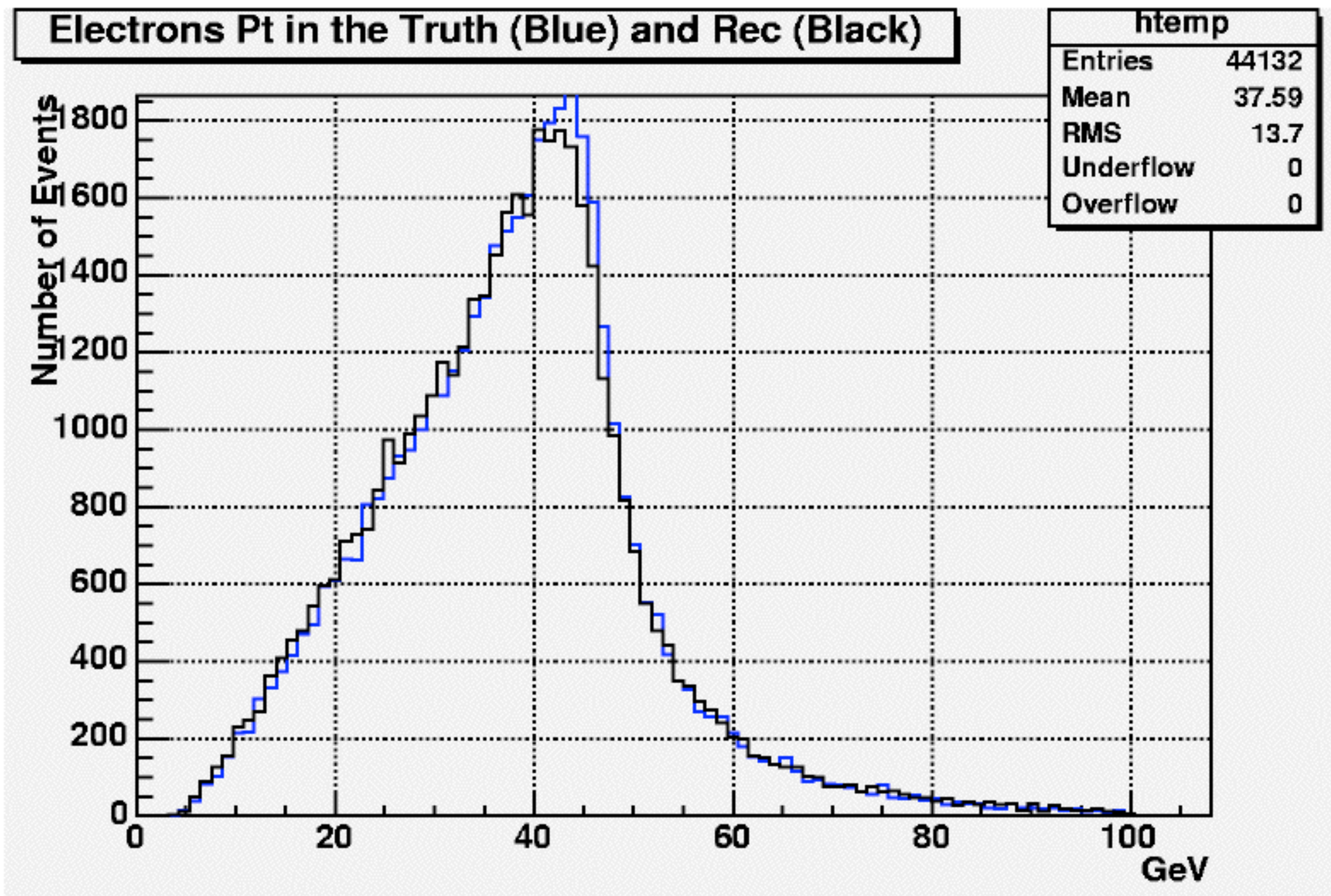
Electron ID Results

Z(->ee) + jets MC, Run 003007 Version 10.0.1
http://www.usatlas.bnl.gov/~damazio/log/r003007v1001/



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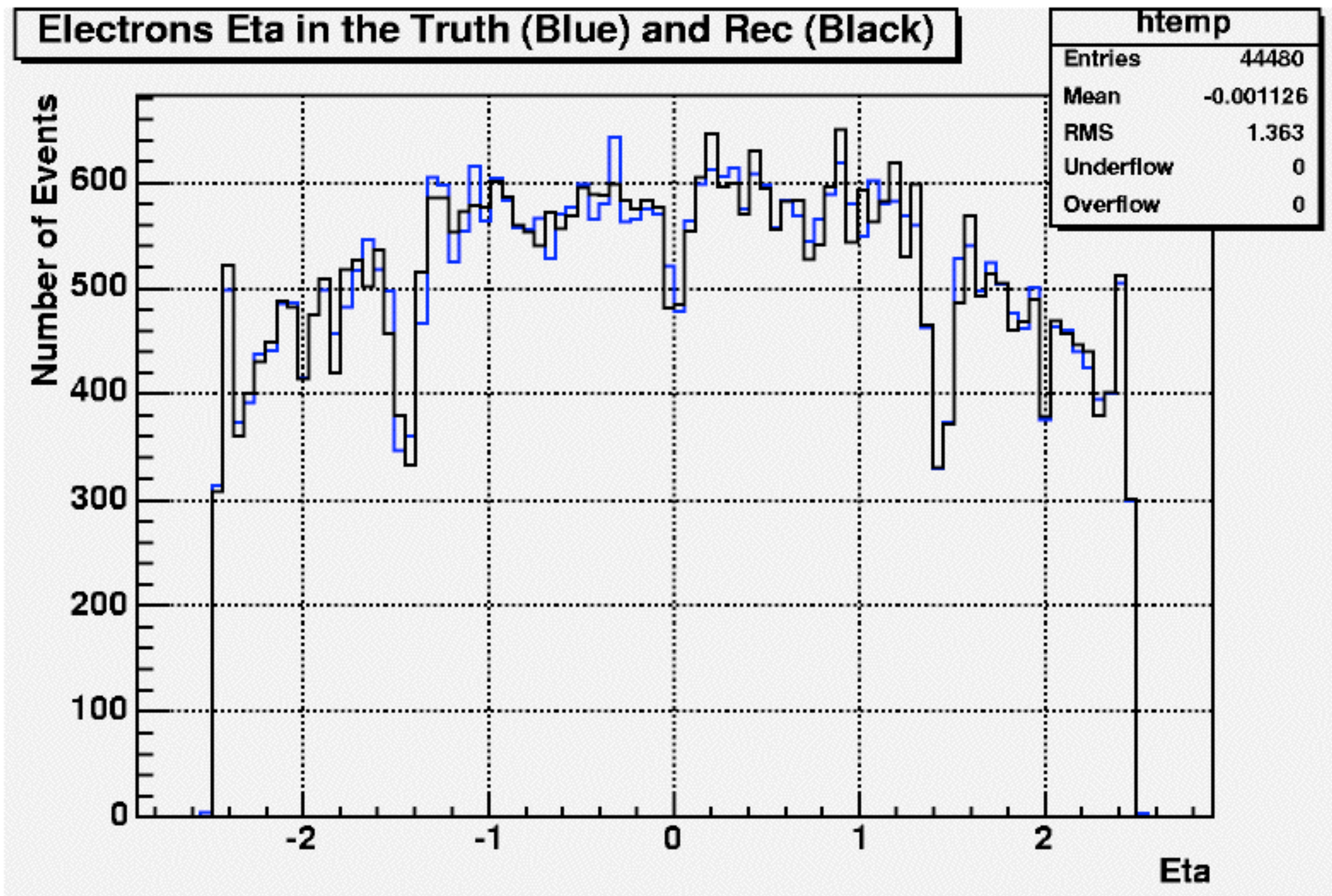

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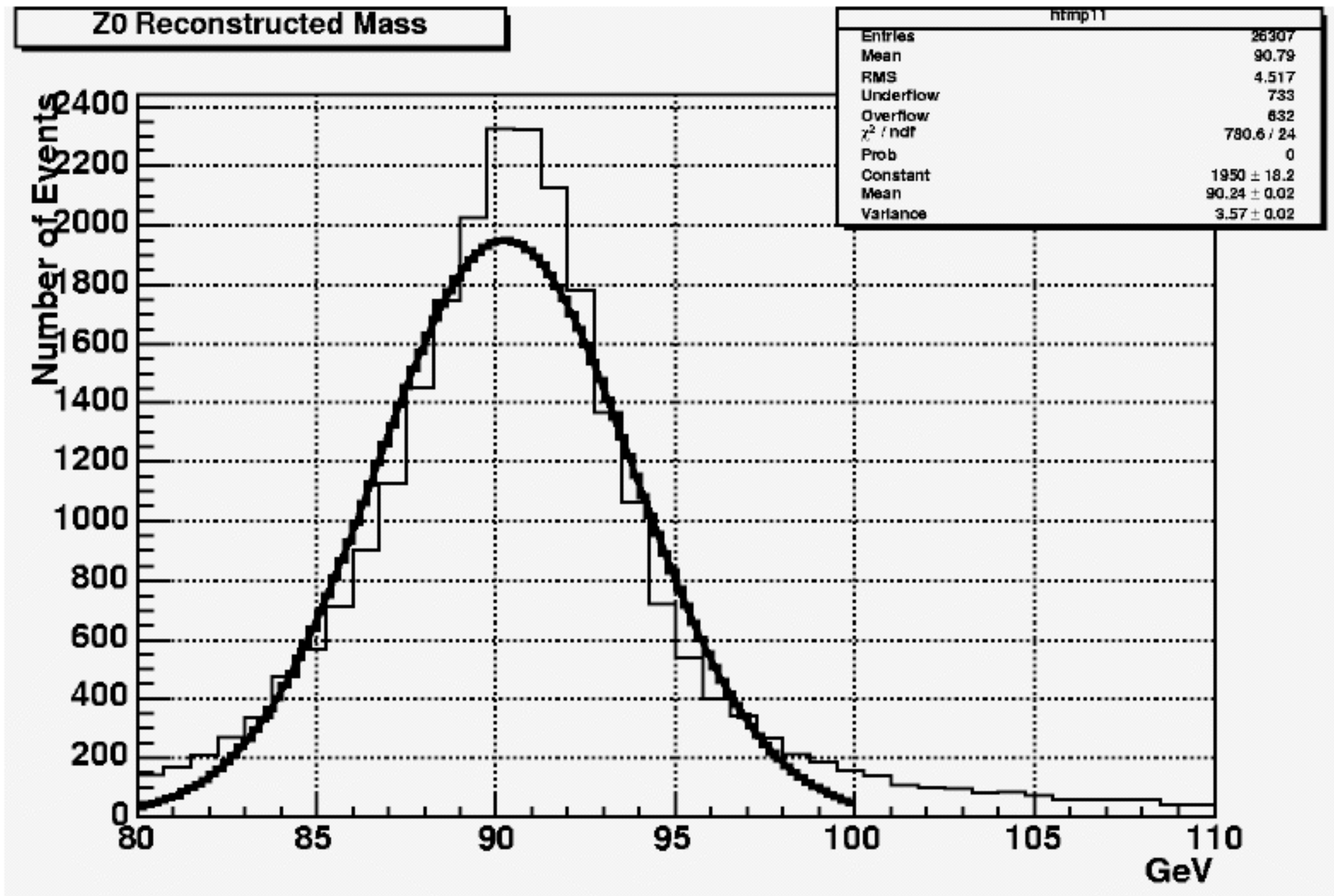

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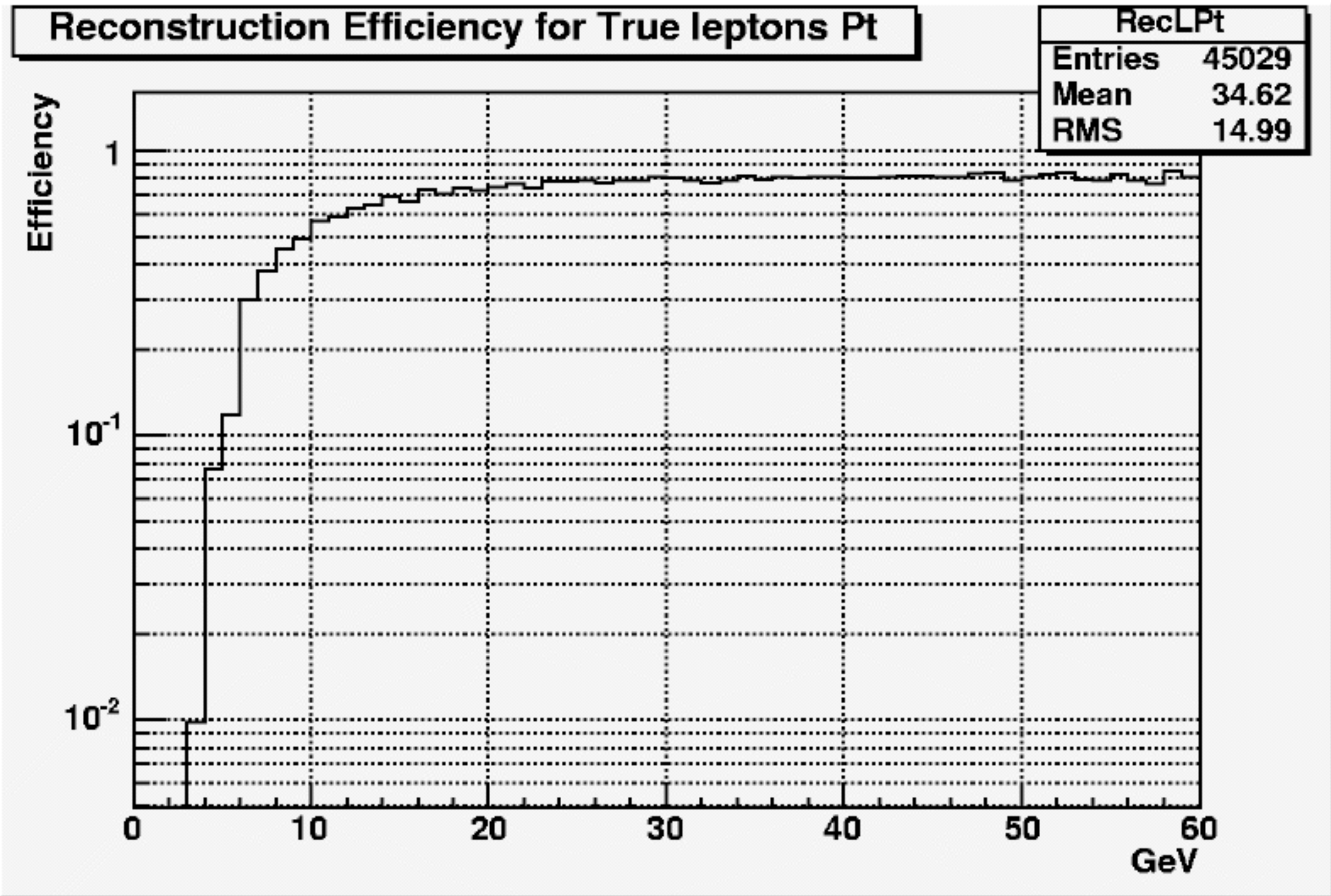

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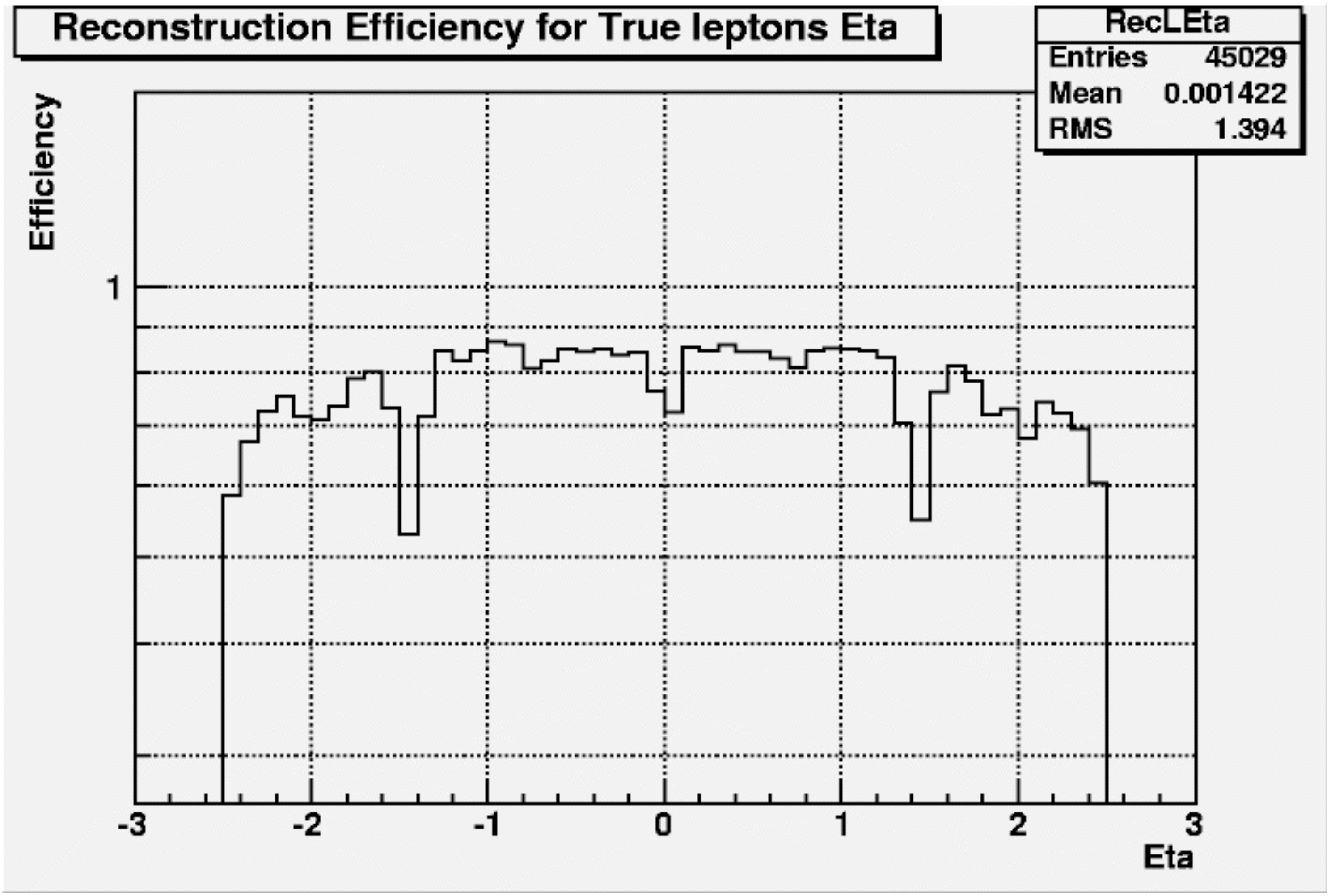

Conclusions

The ATLAS EM calorimeters meet performance specifications.

The ATLAS EM calorimeters are great calorimeters!

ATLAS electron ID is well along.

We will be able to do great physics using electrons and photons!